

Cambridge Judge Business School

Cambridge Centre for Risk Studies

Disaster Impact Assessment Methods for Space Weather Critical Infrastructure Failure: *Input-Output approaches and beyond*

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US Space Weather Workshop

Centre for
Risk Studies



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Presentation Overview

- Disaster impact: *state-of-the-art*
- An overview of input-output methodologies
- Critical evaluation of techniques

Direct and Indirect Cascading Impacts

Direct loss

Indirect loss

Asset
damage

Loss of revenue
to infrastructure
operator

Loss of revenue
to business

Secondary loss of
revenue
to business

Tertiary loss of
revenue
to business

Blackout zone

Transformers
trips

Electricity
company

Steel
production

Car
assembly

Car retail
sales

Approaches to Disaster Impact Assessment

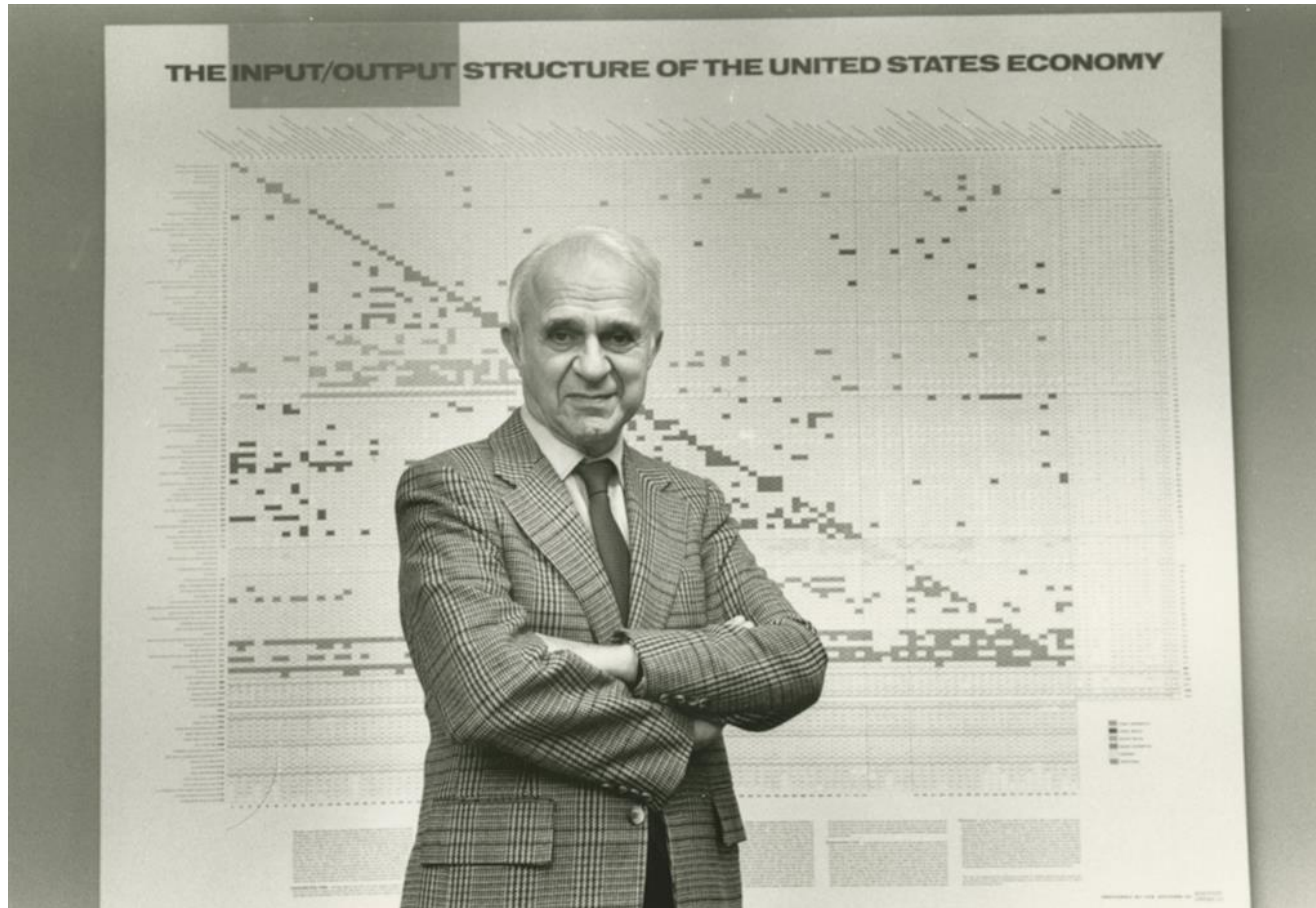
	Input Output (IO)	Computable General Equilibrium (CGE)	Econometrics	Cost-Benefit Analysis
Advantages				
Disadvantages				

What is Input-Output Modelling?



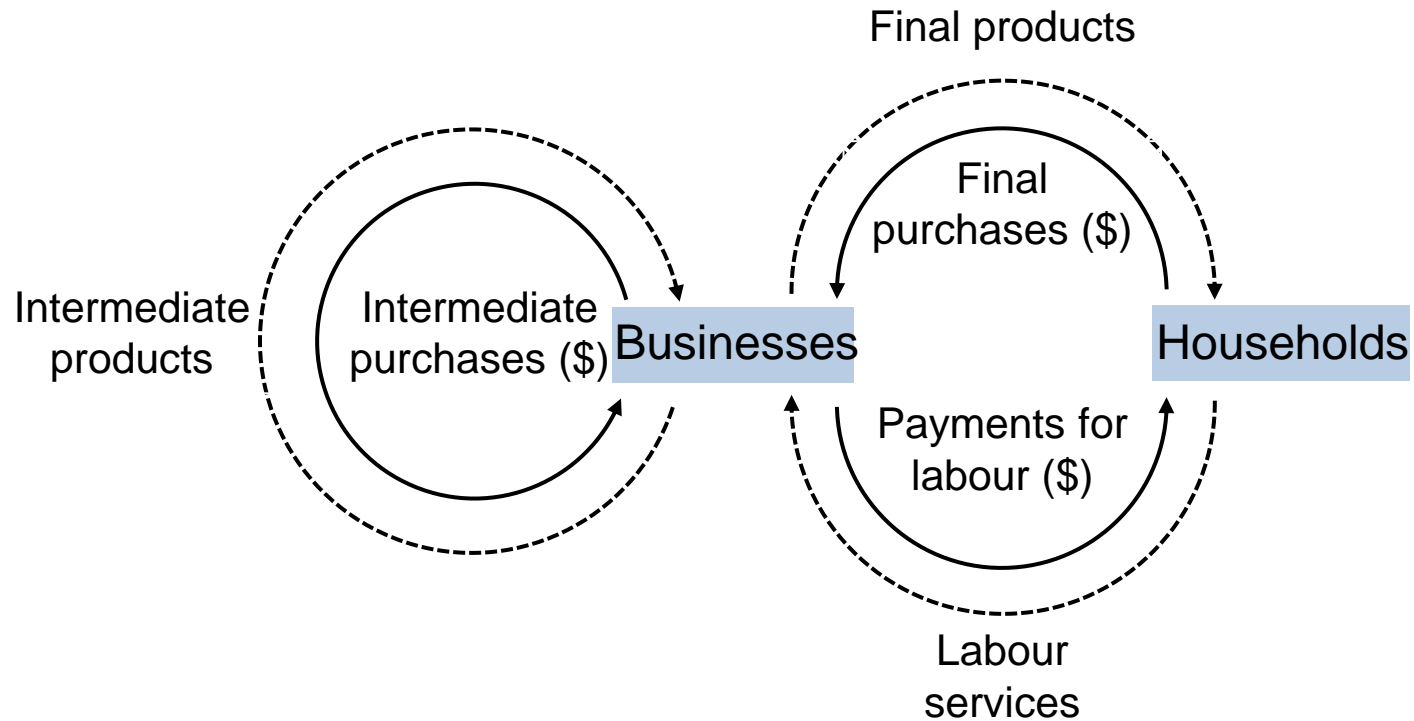
Made fundamental contributions to the development of systems of national accounts and hence greatly improved the basis for empirical economic analysis

What is Input-Output Modelling?



A new method portraying both an entire economy and its fine structure by plotting the production of each industry against its consumption from every other

A Simplified Model of the Economy



General Structure of an Input Output Table

Purchases from intermediate demand

*Sales to
intermediate
demand*

Transaction matrix (**Z**)

Sales to final
demand (**y**)

Total output
(**x**)

Value Added (**v**)

Total input (**x**)

L

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1} \mathbf{y}$$

x = Total output vector

I = Identity matrix

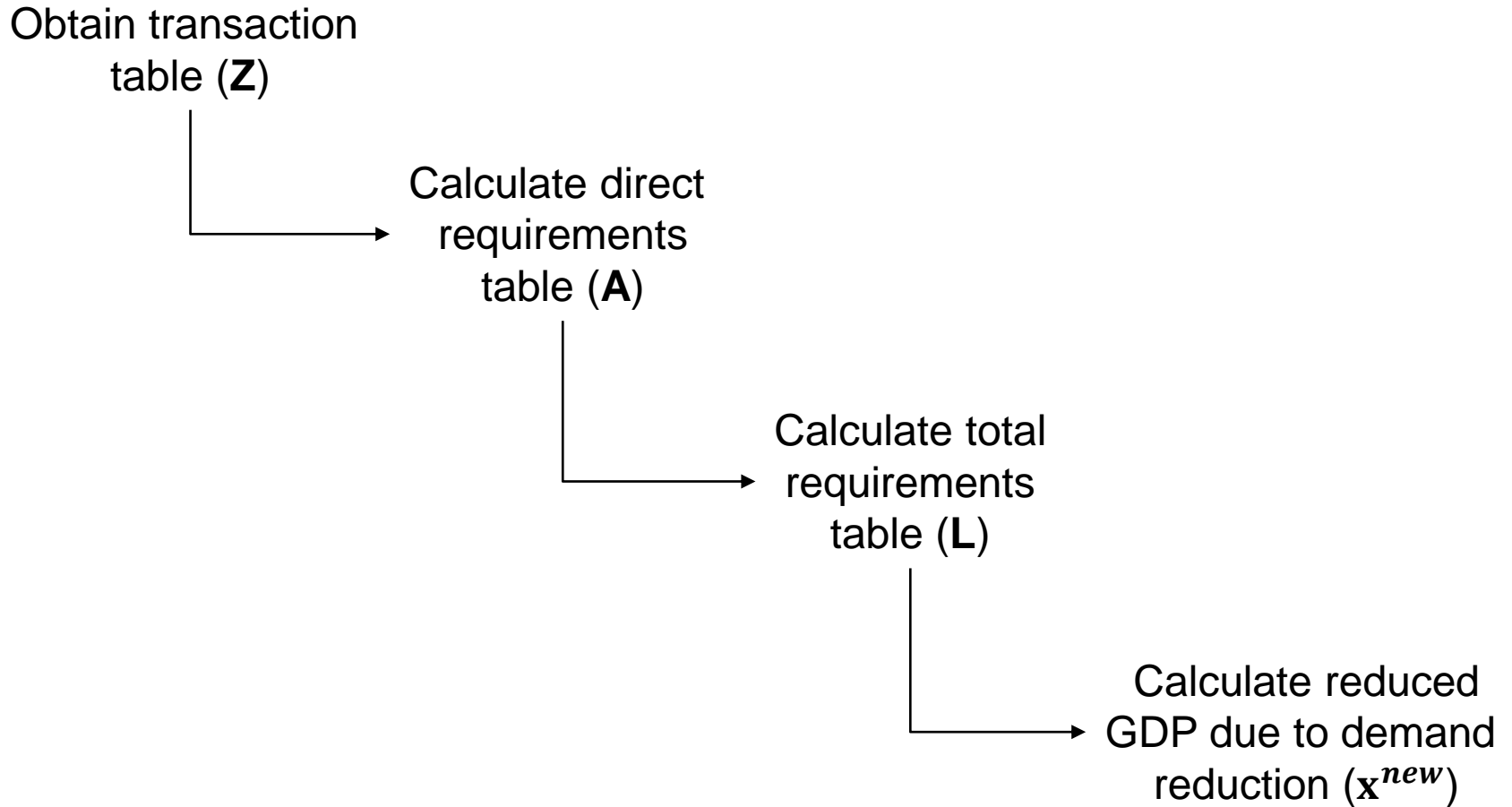
A = Technical coefficients matrix

y = Final demand

L = Leontief inverse

*We want to find the reduction
in output from space weather!*

Methodological Sequence



Basic Transactions Table (Z matrix)

Units: Millions of USD

		PRODUCERS AS CONSUMERS								FINAL DEMAND			Total Output
		Agric.	Mining	Metals	Electricity	Petrochem	Manuf.	Transp.	Services	House-holds	Govt.	Capital	
PRODUCERS	Agric.						10						
	Mining						5						
	Metals						60						
	Electricity						20						
	Petrochem						30						
	Manuf.	20	20	20	10	20	50	40	20	120	20	60	400
	Transp.						20						
	Services						40						
	Value Added						165						
	Total inputs						400						

$$x_i = z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i = \sum_{j=1}^n z_{ij} + f_i$$

Basic Transactions Table (Z matrix)

Units: Millions of USD

		PRODUCERS AS CONSUMERS								FINAL DEMAND			Total Output
		Agric.	Mining	Metals	Electricity	Petrochem	Manuf.	Transp.	Services	Households	Govt.	Capital	
PRODUCERS	Agric.	60	0	0	0	5	10	0	0	80	25	10	190
	Mining	5	5	20	30	30	5	0	0	5	10	5	115
	Metals	5	10	20	5	5	60	5	0	5	10	10	135
	Electricity	10	10	30	10	30	20	20	10	40	10	0	190
	Petrochem	20	10	10	50	40	30	30	5	30	10	5	240
	Manuf.	20	20	20	10	20	50	40	20	120	20	60	400
	Transp.	20	10	5	5	5	20	10	30	50	20	0	175
	Services	10	10	10	10	10	40	20	50	70	30	0	260
	Value Added	40	40	20	70	95	165	50	145	GDP = 625			
	Total inputs	190	115	135	190	240	400	175	260				

$$x_i = z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i = \sum_{j=1}^n z_{ij} + f_i$$

Direct Requirements Table (A Matrix)

Also known as the 'technical coefficients' matrix or input-output table

		PRODUCERS AS CONSUMERS								FINAL DEMAND			Total Output
		Agric.	Mining	Metals	Electricity	Petrochem	Manuf.	Transp.	Services	Households	Govt.	Capital	
PRODUCERS	Agric.						0.03						
	Mining						0.01						
	Metals						0.15						
	Electricity						0.05						
	Petrochem						0.08						
	Manuf.	0.11	0.17	0.15	0.05	0.08	0.13	0.23	0.08				1
	Transp.						0.05						
	Services						0.10						
	Value Added						0.41						
	Total inputs						1						

Production recipe

$$a_{ij} = \frac{z_{ij}}{x_j}$$

Direct Requirements Table (A Matrix)

Also known as the 'technical coefficients' matrix

		PRODUCERS AS CONSUMERS								FINAL DEMAND			Total Output
		Agric.	Mining	Metals	Electricity	Petrochem	Manuf.	Transp.	Services	House-holds	Govt.	Capital	
PRODUCERS	Agric.	0.32	0.00	0.00	0.00	0.02	0.03	0.00	0.00				
	Mining	0.03	0.04	0.15	0.16	0.13	0.01	0.00	0.00				
	Metals	0.03	0.09	0.15	0.03	0.02	0.15	0.03	0.00				
	Electricity	0.05	0.09	0.22	0.05	0.13	0.05	0.11	0.04				
	Petrochem	0.11	0.09	0.07	0.26	0.17	0.08	0.17	0.02				
	Manuf.	0.11	0.17	0.15	0.05	0.08	0.13	0.23	0.08				
	Transp.	0.11	0.09	0.04	0.03	0.02	0.05	0.06	0.12				
	Services	0.05	0.09	0.07	0.05	0.04	0.10	0.11	0.19				
	Value Added	0.21	0.35	0.15	0.37	0.40	0.41	0.29	0.56				
	Total inputs	1	1	1	1	1	1	1	1				

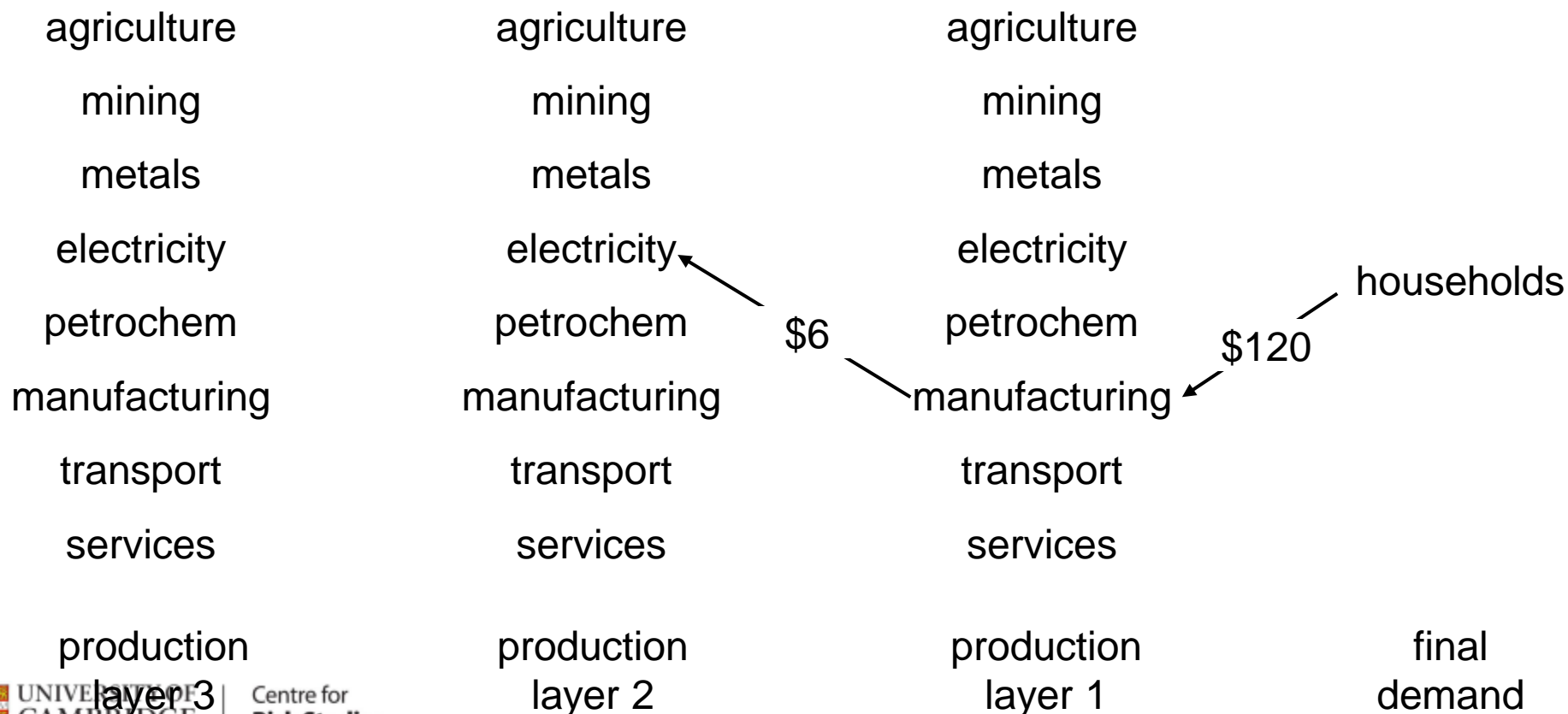
		purchasing sectors							
		agr.	min.	met.	ele.	pet.	man.	tra.	ser.
selling sectors	agriculture	0.32	0	0	0	0.02	0.03	0	0
	mining	0.03	0.04	0.15	0.16	0.13	0.01	0	0
	metals	0.03	0.09	0.15	0.03	0.02	0.15	0.03	0
	electricity	0.05	0.09	0.22	0.05	0.13	0.05	0.11	0.04
	petrochem	0.11	0.09	0.07	0.26	0.17	0.08	0.17	0.02
	manufacturing	0.11	0.17	0.15	0.05	0.08	0.13	0.23	0.08
	transport	0.11	0.09	0.04	0.03	0.02	0.05	0.06	0.12
	services	0.05	0.09	0.07	0.05	0.04	0.1	0.11	0.19

How much electricity is used to make final manufacturing products?



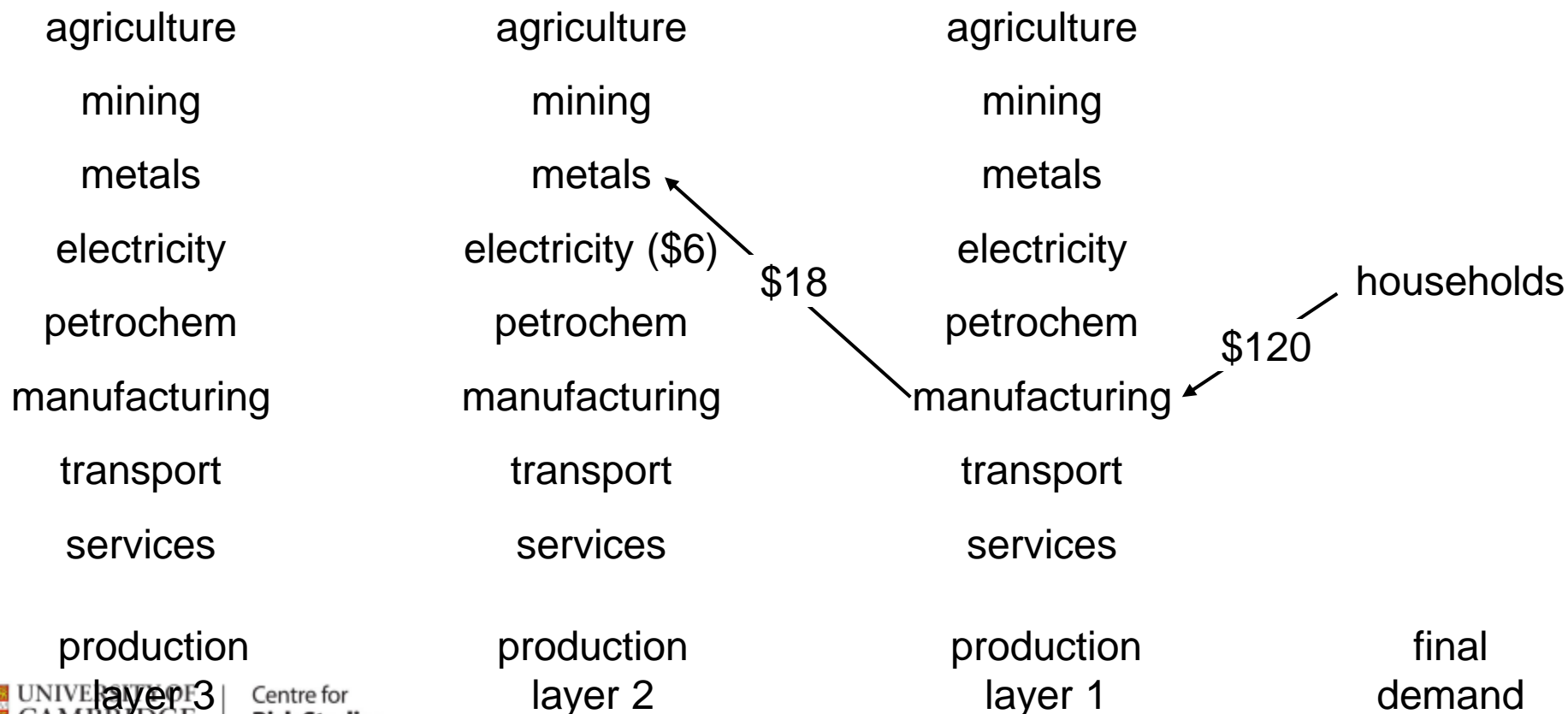
		purchasing sectors							
		agr.	min.	met.	ele.	pet.	man.	tra.	ser.
selling sectors	agriculture	0.32	0	0	0	0.02	0.03	0	0
	mining	0.03	0.04	0.15	0.16	0.13	0.01	0	0
	metals	0.03	0.09	0.15	0.03	0.02	0.15	0.03	0
	electricity	0.05	0.09	0.22	0.05	0.13	0.05	0.11	0.04
	petrochem	0.11	0.09	0.07	0.26	0.17	0.08	0.17	0.02
	manufacturing	0.11	0.17	0.15	0.05	0.08	0.13	0.23	0.08
	transport	0.11	0.09	0.04	0.03	0.02	0.05	0.06	0.12
	services	0.05	0.09	0.07	0.05	0.04	0.1	0.11	0.19

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		purchasing sectors							
		agr.	min.	met.	ele.	pet.	man.	tra.	ser.
selling sectors	agriculture	0.32	0	0	0	0.02	0.03	0	0
	mining	0.03	0.04	0.15	0.16	0.13	0.01	0	0
	metals	0.03	0.09	0.15	0.03	0.02	0.15	0.03	0
	electricity	0.05	0.09	0.22	0.05	0.13	0.05	0.11	0.04
	petrochem	0.11	0.09	0.07	0.26	0.17	0.08	0.17	0.02
	manufacturing	0.11	0.17	0.15	0.05	0.08	0.13	0.23	0.08
	transport	0.11	0.09	0.04	0.03	0.02	0.05	0.06	0.12
	services	0.05	0.09	0.07	0.05	0.04	0.1	0.11	0.19

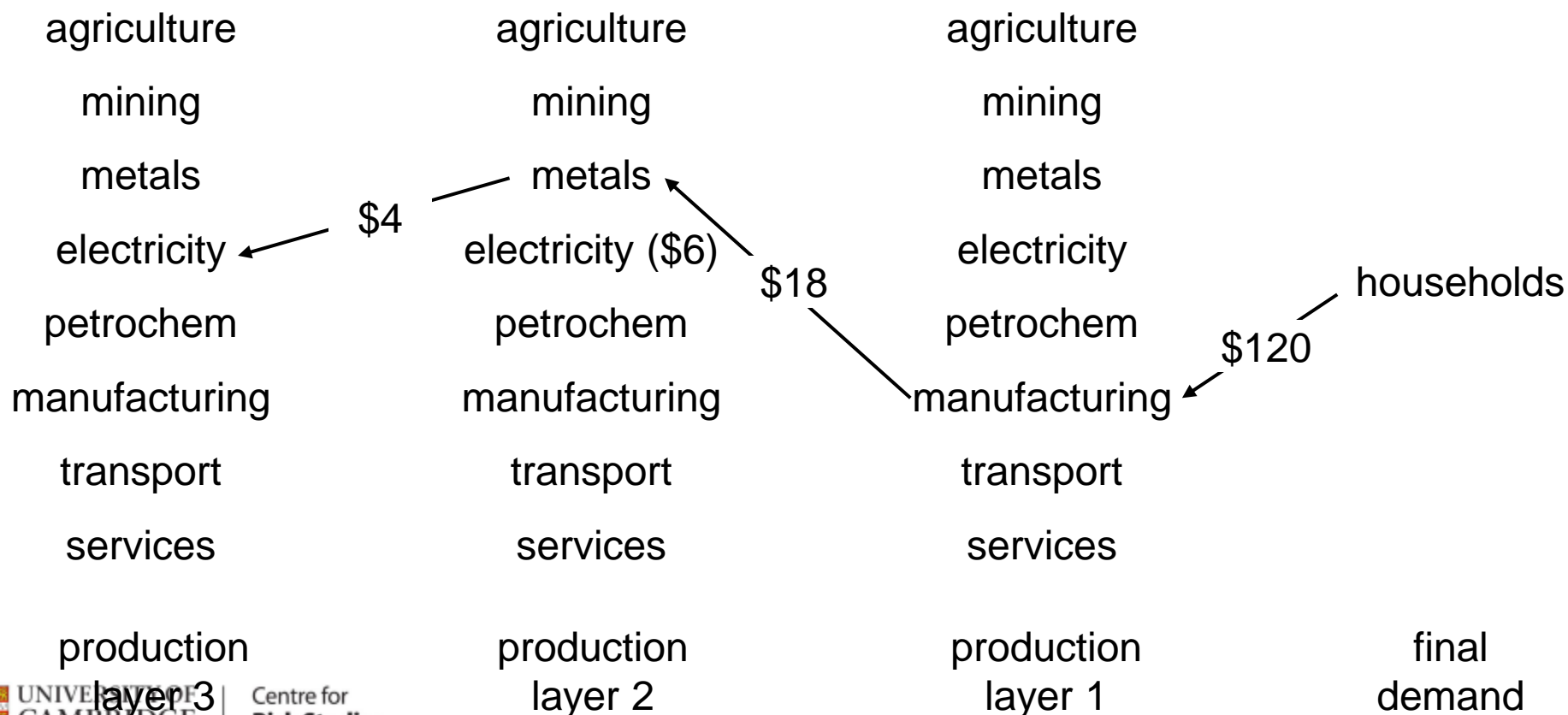
How much electricity is used to make final manufacturing products?



selling sectors

	purchasing sectors							
	agr.	min.	met.	ele.	pet.	man.	tra.	ser.
agriculture	0.32	0	0	0	0.02	0.03	0	0
mining	0.03	0.04	0.15	0.16	0.13	0.01	0	0
metals	0.03	0.09	0.15	0.03	0.02	0.15	0.03	0
electricity	0.05	0.09	0.22	0.05	0.13	0.05	0.11	0.04
petrochem	0.11	0.09	0.07	0.26	0.17	0.08	0.17	0.02
manufacturing	0.11	0.17	0.15	0.05	0.08	0.13	0.23	0.08
transport	0.11	0.09	0.04	0.03	0.02	0.05	0.06	0.12
services	0.05	0.09	0.07	0.05	0.04	0.1	0.11	0.19

How much electricity is used to make final manufacturing products?



Obtaining the Total Requirements Matrix (L)

I		A		(I - A)													
1	0	0	0	0	0	0.45	0.01	0.00	0.02	0.00	0.00	0.55	-0.01	0.00	-0.02	0.00	0.00
0	1	0	0	0	0	0.21	0.36	0.07	0.02	0.02	0.02	-0.21	0.64	-0.07	-0.02	-0.02	-0.02
0	0	1	0	0	0	0.14	0.29	0.22	0.01	0.02	0.08	-0.14	-0.29	0.78	-0.01	-0.02	-0.08
0	0	0	1	0	0	0.03	0.00	0.00	0.34	0.01	0.00	-0.03	0.00	0.00	0.66	-0.01	0.00
0	0	0	0	1	0	0.01	0.15	0.14	0.11	0.30	0.07	-0.01	-0.15	-0.14	-0.11	0.70	-0.07
0	0	0	0	0	1	0.01	0.02	0.14	0.16	0.15	0.16	-0.01	-0.02	-0.14	-0.16	-0.15	0.84

- =

$$(I - A)^{-1} = L$$

0.55	-0.01	0.00	-0.02	0.00	0.00	1.85	0.03	0.01	0.07	0.01	0.00
-0.21	0.64	-0.07	-0.02	-0.02	-0.02	0.69	1.69	0.18	0.09	0.07	0.06
-0.14	-0.29	0.78	-0.01	-0.02	-0.08	0.61	0.67	1.39	0.11	0.10	0.16
-0.03	0.00	0.00	0.66	-0.01	0.00	0.09	0.02	0.01	1.53	0.04	0.01
-0.01	-0.15	-0.14	-0.11	0.70	-0.07	0.34	0.52	0.36	0.32	1.50	0.18
-0.01	-0.02	-0.14	-0.16	-0.15	0.84	0.22	0.26	0.31	0.36	0.29	1.26

The Leontief matrix ($L = (I - A)^{-1}$) uniquely summarises all direct and indirect network relationships in the economy

Total Requirements Matrix (L)

		PRODUCERS AS CONSUMERS								FINAL DEMAND			Total Output
		Agric.	Mining	Metals	Electricity	Petrochem	Manuf.	Transp.	Services	House-holds	Govt.	Capital	
PRODUCERS	Agric.						0.06						
	Mining						0.13						
	Metals						0.26						
	Electricity						0.21						
	Petrochem						0.26						
	Manuf.	0.38	0.38	0.42	0.25	0.27	1.32	0.44	0.21				
	Transp.						0.14						
	Services						0.25						
	Value Added												
	Total inputs												

Total Requirements Matrix (L)

		PRODUCERS AS CONSUMERS								FINAL DEMAND			Total Output
		Agric.	Mining	Metals	Electricity	Petrochem	Manuf.	Transp.	Services	House-holds	Govt.	Capital	
PRODUCERS	Agric.	1.49	0.02	0.03	0.02	0.05	0.06	0.03	0.01				
	Mining	0.16	1.16	0.33	0.29	0.25	0.13	0.13	0.05				
	Metals	0.15	0.21	1.31	0.13	0.12	0.26	0.15	0.06				
	Electricity	0.24	0.25	0.44	1.21	0.27	0.21	0.27	0.12				
	Petrochem	0.39	0.30	0.37	0.48	1.38	0.26	0.40	0.14				
	Manuf.	0.38	0.38	0.42	0.25	0.27	1.32	0.44	0.21				
	Transp.	0.25	0.18	0.16	0.12	0.11	0.14	1.16	0.19				
	Services	0.25	0.25	0.28	0.19	0.18	0.25	0.28	1.32				
	Value Added												
	Total inputs												

Calculating Total Loss Due to a Reduction in Final Demand (from a blackout)

$$\left(\begin{array}{c} \text{Amount} \\ \text{Produced} \\ \mathbf{x} \end{array} \right) = \left(\begin{array}{c} \mathbf{x} = \mathbf{L} \mathbf{y} \\ \text{Internal} \\ \text{Demand} \\ \mathbf{L} \end{array} \right) \left(\begin{array}{c} \text{Final} \\ \text{Demand} \\ \mathbf{y} \end{array} \right)$$

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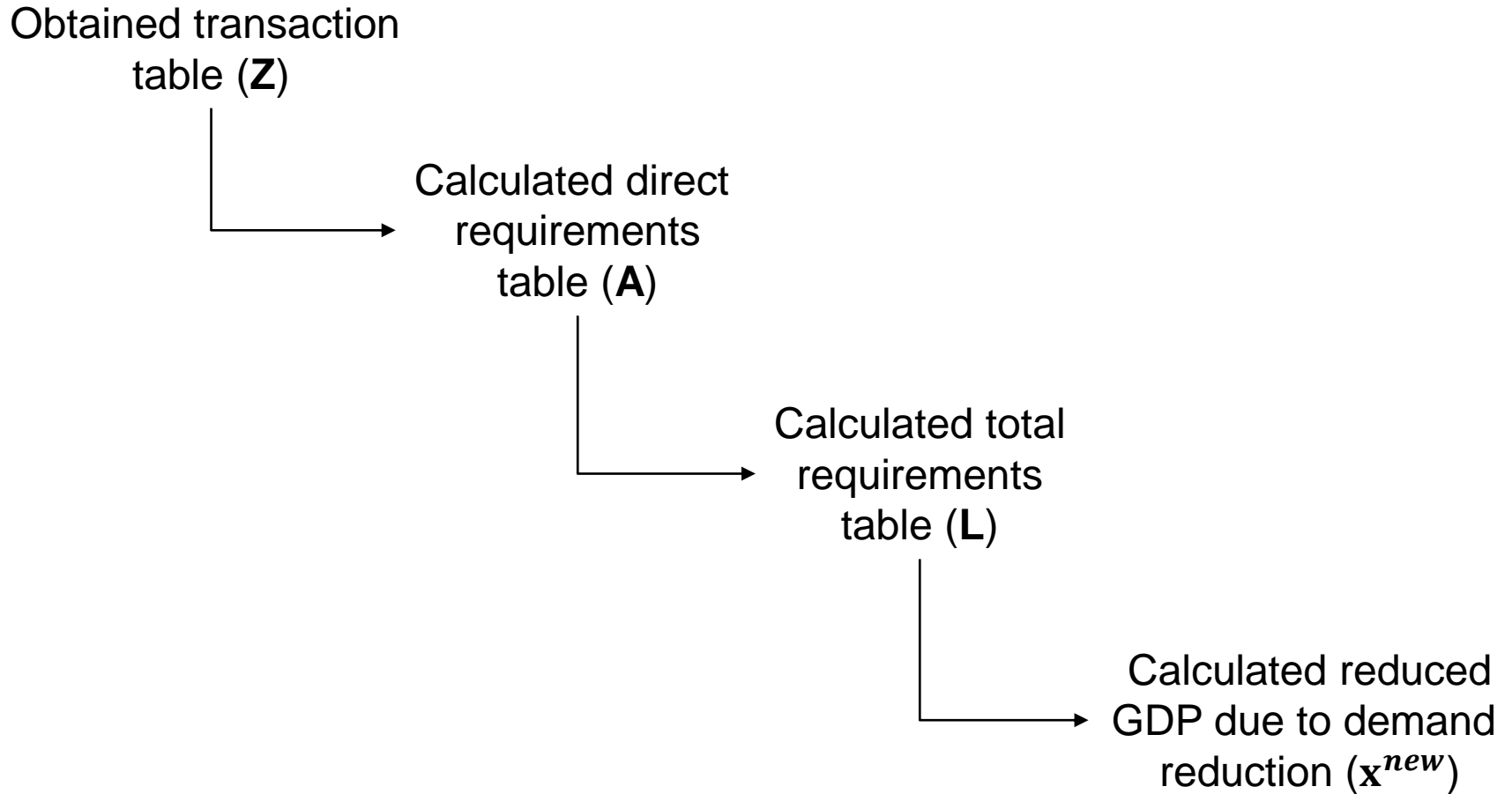
$$\begin{pmatrix} \text{Amount Produced} \\ \mathbf{x} \end{pmatrix} = \begin{pmatrix} \mathbf{x} = \mathbf{L}\mathbf{y} \\ \text{Internal Demand} \\ \mathbf{L} \end{pmatrix} \begin{pmatrix} \text{Final Demand} \\ \mathbf{y} \end{pmatrix}$$

$$\begin{pmatrix} \text{Degraded Output} \\ \mathbf{x}^{new} \end{pmatrix} = \begin{pmatrix} \mathbf{x}^{new} = \mathbf{L}\mathbf{y}^{new} \\ \text{Internal Demand} \\ \mathbf{L} \end{pmatrix} \begin{pmatrix} \text{Degraded Final Demand} \\ \mathbf{y}^{new} \end{pmatrix}$$

\mathbf{x}^{new} is the degraded output (GDP) due to a reduction in final demand due to space weather

(This is a simplification:
See Miller & Blair, 2009 for a complete overview)

Methodological Sequence



Overview of Approaches

	Input Output	Computable General Equilibrium	Econometrics	Cost-Benefit Analysis
Advantages	Simplicity	Addresses market behaviours	Good forecasting	Simplicity
	Clear distinction between direct and indirect impacts	Can model a broad range of effects	Rigorous validation	Attempts to capture all costs and benefits
	Well suited to distributional analysis	Can examine distributional impacts	No major biases in estimating impacts	Applies expert knowledge and expertise to generate cost estimates
	Excellent framework for data collection	Can model long-term recovery effects	Incorporates uncertainty	Model transparency
	Provides transparent view of the economy	Can model impacts across a range of macroeconomic variables	Does not assume market equilibrium	Single unit-measurement so costs and benefits can be easily compared
Disadvantages	Rigid due to linearity	Intended for long-run equilibrium analysis	Not well suited to modelling rare events	Does not account for economic multipliers
	Ignores agent behavioural response to disaster	Usually provides over optimistic results because of flexibility response	Difficult to obtain disaggregated regional data	Subjective costs and complications
	Inadequately deals with monetary interventions	No explicit distinction between direct and indirect effects	No explicit distinction between direct and indirect effects	Single unit-measurement assumes all things can be easily compared
	Relies on market-equilibrium while disasters represent disequilibrium	Assumes all agents optimise	Model is based on historical experience which might not hold in the future	
	Characterised as providing over pessimistic results	Assumes agents have perfect information	Inadequately allows for economic multiplier effects	

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Conclusion

1. An illustrated example of how to calculate the GDP impact of space weather using input-output
2. There are some distinct benefits of IO:
 - Separation of direct and indirect impacts
 - Transparent and simple
 - Can be integrated with other models
3. IO does not include the behavioural responses to a disaster

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